

TRAWLED CATCHES IN NORTHERN MORETON BAY I. EFFECTS OF SAMPLING VARIABLES

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ABSTRACT

An analysis of variance approach was applied to catches of 60 species summed over 13 times, to evaluate the effects of sampling alternatives. These were: port and starboard nets, hauls with and into the tide, catches at midday and at dusk, and catches at three selected sites.

Use of Box and Cox transformations showed that each species required a different transformation to give a normal distribution.

Analyses were restricted to first order effects and second order interactions. In the former the hierarchy of importance of the sampling alternatives was sites >> time of day > port and starboard > tidal direction. In the latter the most important interaction was midday, dusk/the three sites. Various possible 'explanations' of interaction effects were attempted, but these were at best unconvincing. Most of the interactions appear to be due to random variations in the data.

INTRODUCTION

Enlargement of the Brisbane Airport has potential effects on a variety of marine biotas, and various 'before the event' studies have already been made, of which the most recent are Stephenson (1980a, b, c). Young and Wadley (1979) have also studied the catches of certain of the areas of interest using a small-mesh beam trawl, but no investigations had been made of the catches obtained by prawn trawlers using commercial nets. It was felt that of the possible effects of the constructional work at the Airport, those on the catches of prawn trawlers would be of the greatest economic significance, and for this reason the present investigation was commenced in early April 1979.

The immediate question is the acceptability of catches made by commercial prawn trawling gear. Jones (1973) was able to use catches from such gear effectively in his analyses of nekto-benthic invertebrates in Moreton Bay. More recently Stephenson and Burgess (1980) and Burgess (1980) have confirmed this. The present gear was identical with that used by Burgess (1980).

The present work involves analyses of the first year of data at three sampling sites: No. 1, Bramble Bay; No. 2, Redcliffe; and No. 3, S. of Middle Banks. Bramble Bay was chosen because it is adjacent to the Airport (ca 4 km), and may be affected by the partial filling of Serpentine Creek, and dredging of Jackson's Creek (see Fig. 1). The depth was ca 4 m and bottom primarily mud. Redcliffe is in the nature of a control site, distant from Airport activities; depth was ca 7 m and the bottom mud. The site south of the Middle Banks is south of the area from which sand fill for the Airport is to be obtained. Trawling could not be closer to the dredging site because the latter area is too confined for safe trawling. The site is in an area extensively used by commercial prawn trawlers; depth is ca 24 m and the bottom sandy mud.

Samples were collected at intervals of lunar months (28 days) beginning early April 1979 and extending for one year (13 months). At each site at each month three other sampling variables were involved: port and starboard nets, trawling with and against the tide, and sampling at midday and

dusk. Hence sampling involved 13 months \times 3 sites \times 2 times of day \times 2 tidal directions \times 2 nets, i.e. 312 samples in all. For each sample counts were made of the species collected, and for present purposes 60 species were considered. Of the five

sampling variables, the main interest is in months and sites, and these (the 'prime variables') can be analysed using a sampling dimension of 13 months \times 3 sites, with summing of catches over the other variables.

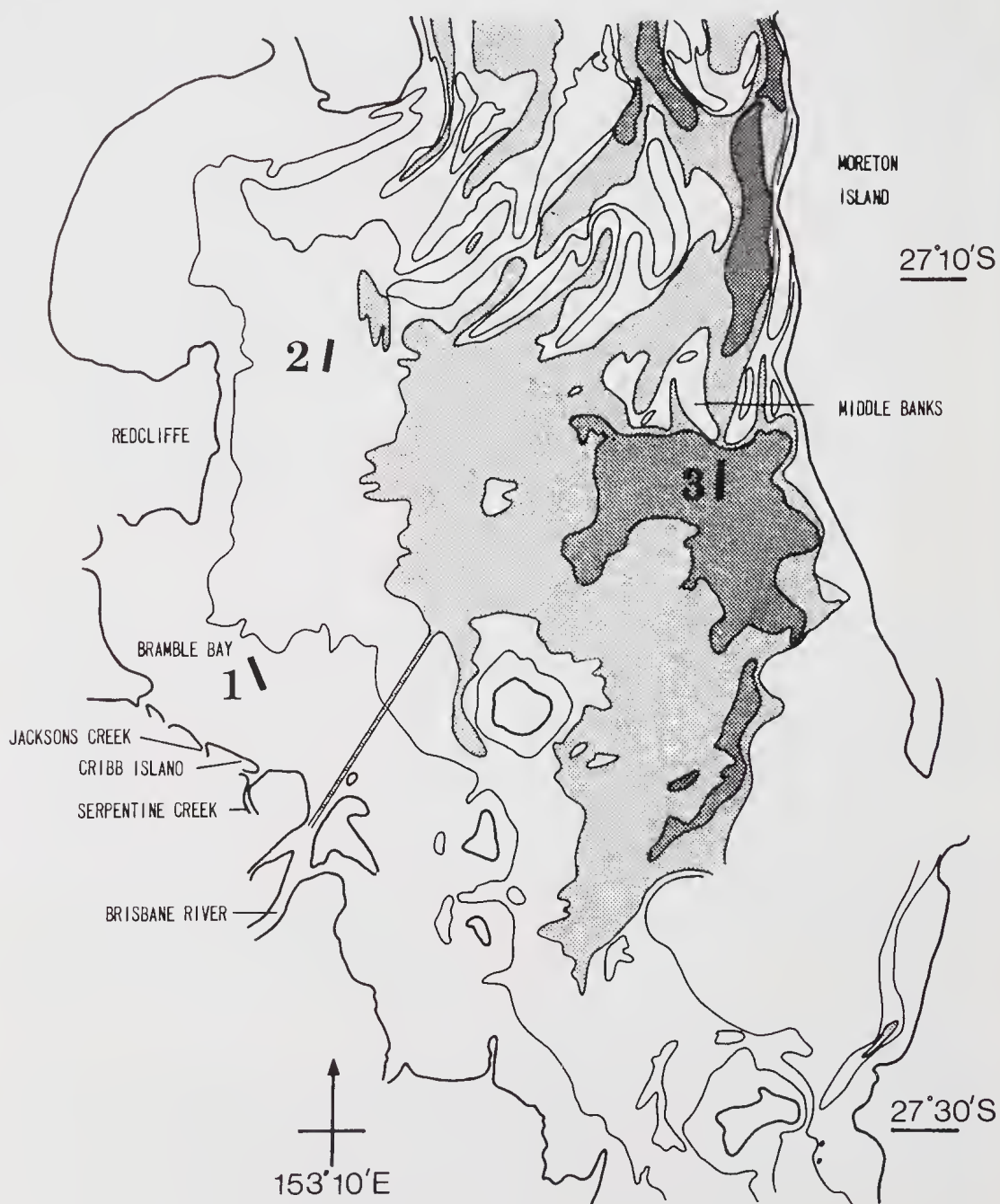


FIG. 1: Moreton Bay showing sites of sampling (1-3) and localities mentioned in the text.

Prior to so doing, it was thought to be of interest to evaluate the effects of the three remaining pairs of sampling variables (port/starboard nets, with/against tide, and midday/dusk). We can thus determine firstly whether port and starboard nets catches can be regarded as authentic replicates, as might be expected. Jones (1973) concluded that direction of trawling relative to the tide had very little effect on catches of nekto-benthic invertebrates, and the present more extensive data allows checking of his conclusions as well as extending them to the trawled fishes. While catches at midday and dusk are almost certainly different, quantification of results on the individual species is of interest from the light it throws on feeding habits and temporal 'niches'. Present analyses also cover one of the 'prime variables' — sites.

Catches at three sites are expected to be different and Stephenson and Burgess (1980) should be consulted for site patterns of species of fish in Moreton Bay. By using only three sites and establishing as we do, species which have significantly different site-distributions, we can reverse the approach of Stephenson and Burgess. The latter involved first establishing patterns by use of cluster analyses and then performing 'pseudo-*F*' tests on species recordings. (See Stephenson and Campbell 1977 for the 'pseudo-*F*' test). In the present case we use *F* tests first and then effect clustering using species with significantly different site-recordings.

SAMPLING PROCEDURES AND FORM OF THE DATA

Catches were of 15 min duration, including the time lowering and raising the net. It is appreciated that there will be some contamination of catches by midwater and surface water species, particularly at the deeper site 3, with shorter hauls this contamination would have been proportionally greater. With each haul catches from port and starboard nets were considered separately. One haul was made either into or with the tide and after ca 30 min a second was made in the reverse direction. At each site the procedure was repeated at midday and dusk, giving a total of 8 catches for each site at each time.

In each catch individuals of each well-known species were counted on board and not retained. All specimens of the less well-known species were preserved, identified at base and counted. Fish identifications were from Marshall (1964), Munro (1967), and Grant (1975) supplemented by invaluable assistance from Mrs. Deborah Burgess

and Professor J.M. Thomson. Cephalopod identifications were made by Mrs. Pauline Dayaratne, Ministry of Fisheries, Colombo, Sri Lanka. Penaeid prawns were identified mainly from Dall (1957), alpheidids from Banner and Smalley (1969), and the portunid crabs, other decapods and stomatopods by the senior author.

DATA REDUCTION

Study of sampling variables, including interaction effects, involves analysis of variance or related approaches and these become increasingly satisfactory as species become increasingly absent from the samples, for example it is pointless to effect analyses on a species found in only 2/312 cases. Species were ranked by the number of samples of occurrence (ubiquity) and only the 60 species most frequently present of the total of 117 species were considered. Ubiquities ranged from 291 to 27.

The 60 species were then further rearranged to give an abundance hierarchy and allocated code numbers which are given in Appendix 1 together with their systematic names. Subsequent reference to a species is either by code number or by generic name — unless more than one species of a genus is listed.

SELECTION OF ANALYTICAL METHODS

The GLIM software computer package (Baker and Nelder 1978) was used to analyse the sets of data in the present study. Restrictions to the size of data blocks which can be analysed by GLIM on the University of Queensland PDP 10 computer precluded the use of the complete 5-way classification (312 values per species). Values were therefore summed over time (13 times) because this action produced the greatest data condensation; interactions of other sampling variables with time unfortunately were eliminated.

Preliminary analyses of data using GLIM showed that the data did not follow any of the common distributions. It was decided (a) to transform species data to obtain close approximations to normal distributions using Box and Cox transformations (see Appendix 2) and (b) to perform an analyses of variance on the transformed data for each species using GLIM. Models fitted included only first order effects and second order interactions.

TABLE 1: TRANSFORMATIONS AND FIRST AND SECOND ORDER EFFECTS.

Species code no.	Transformations		First order effects				2x2 Second order effects with probability		2x3 Second order effects with probability		
	b	Std error b	P/S	W/I	M/D	S1,2,3	PS/MD	W1/MD	PS/S1,2,3	W1/S1,2,3	MD/S1,2,3
			Larger Prob.	Larger Prob.	Larger Prob.	Largest Prob.			Larger Largest Prob.	Larger Largest Prob.	Larger Largest Prob.
1	0.0752	0.136			M 0.5	2 0.1		1		1, 2 5	M, 1 0.1
2	-0.0688	0.184				2 0.1					
3	-0.227	0.563			M 0.5	3 0.1					D, 1 0.5
4	-0.572	0.339	S 2.5		M 5	3 0.1					
5	0.134	0.352				2 0.1					
6	0.461	0.284				2 0.1					D, 2 5
7	* 0.282	0.121	P 2.5		D 0.1	2 0.1					M, 1 0.1
8	0.486	0.628	P 1		D 0.1						
9	0.153	0.183	P 1		D 0.1	1 0.1					
10	-0.219	0.300	P 2.5		D 0.1	3 0.1					D, 1 0.1
11	0.0439	0.170		W 0.1		3 0.1					
12	0.167	0.136	P 2.5		D 0.5	3 0.1					
13	-0.289	0.287			D 0.5	2 0.1					
14	0.110	0.140	S 0.1		M 0.1	1 0.1		0.5			M, 2 2.5
15	-0.188	0.152	P 2.5	W 1		3 0.1					
16	* 0.816	0.245		W 5	D 0.1	1 0.5	5				M, 1 5
17	-0.379	0.161				1 0.1					
18	0.237	0.233				1 0.1					D, 2 0.5
19	0.155	0.312				3 0.5					
20	0.131	0.168			D 5	3 0.1					
21	* -0.449	0.177				3 0.1					
22	-0.343	0.509			D 0.1	3 2.5	5	1	S, 2 5	W, 1 5	
23	* -0.589	0.190	P 5			3 0.1	1		S, 1 2.5		M, 2 0.5
24	0.241	0.165			M 0.5	1 0.1					M, 1 2.5
25	0.112	0.157			D 0.1	2 0.5		5			
26	0.153	0.176			D 2.5	1 0.1					
27	-0.0563	0.172				3 0.1					
28	-0.123	0.179				3 0.1			P, 1 2.5	W, 2 5	
29	-0.143	0.249			D 0.5	3 0.1					
30	-0.0689	0.184		1 2.5		1 0.1					
31	-0.350	0.197			D 0.1	2 0.1					D, 1 0.1
32	0.153	0.198	P 2.5		D 2.5	3 0.1				1, 3 5	D, 1 2.5
33	-0.164	0.199				2 0.1					D, 1 0.5
34	-0.226	0.200	S 2.5			3 0.1	2.5		S, 2 0.5		
35	0.298	0.239				3 0.1					
36	-0.409	0.221				3 0.1					
37	0.0670	0.0451	P 2.5		D 2.5						
38	-0.205	0.241				1 0.5					
39	* 0.0745	0.00742						2.5			
40	-0.161	0.235	P 5	W 5		3 0.1			S, 2 1		
41	* -0.560	0.210				3 0.5	5				
42	-0.343	0.218			D 0.1	1 0.1					M, 1 2.5
43	-0.435	0.262			M 0.5	3 0.1					M, 2 0.5
44	* -1.135	0.297			D 1	3 0.1					
45	-0.512	0.252		1 0.5	M 0.1	1 0.1				1, 2 0.1	M, 2 0.1
46	0.172	0.245			D 5						D, 1 5
47	-0.143	0.261				3 0.1					
48	* -0.776	0.311				3 0.1					
49	0.0468	0.284									
50	-0.0832	0.271	P 1			3 0.5					

TABLE 1: (Continued)

Species code no.	Transformations		First order effects				2x2 Second order effects with probability		2x3 Second order effects with probability			
	b	Std error b	P/S	W/I	M D	S1,2,3	PS/MD	WI/MD	PS/S1,2,3	WI/S1,2,3	MD/S1,2,3	
			Larger Prob.	Larger Prob.	Larger Prob.	Largest Prob.			Larger Largest Prob.	Larger Largest Prob.	Larger Largest Prob.	
51	*-0.204	0.00251			D 0.1	1 0.1			S, 3 5	W, 3 5	D, 3 2.5	
52	*-0.240	0.00292			D 5	1 0.1					D, 1 2.5	
53	-0.184	0.287				1 1						
54	-0.464	0.309				3 0.1		5	P, 3 5			
55	*-0.438	0.00315			D 2.5	3 0.1						
56	*-0.547	0.00363				3 0.1						
57	*-0.459	0.00334		1 5	D 5	1 0.1					D, 1 0.5	
58	*-0.371	0.00529				1 0.5	2.5	0.5	P, 3 2.5	W, 2 2.5	M, 2 5	
59	*-0.523	0.00402			M 0.5	3 0.1					M, 3 0.5	
60	*-0.524	0.00430	P 2.5			1 0.1						

Probabilities throughout as percentages.

Cols 2 and 3. Value of b used in transformation and standard error. Values of b significantly different from zero indicated by asterisk. Cols 3, 4, 5 and 6. Significant first order effects of port/starboard, with tide/into tide, midday/dusk, and sites 1, 2 and 3 respectively. The larger catches indicated by P or S, W or I, M or D, and 1, 2, or 3 respectively.

Cols 7 and 8. Significant second order effects involving 2x2 factors, with probabilities.

Cols 9, 10, and 11. Significant second order effects involving 2x3 factors. The larger 2 factor catch indicated by alphabetic abbreviation, and the largest 3 factor catch by the site number. Probabilities also given.

RESULTS (SEE TABLE 1)

TRANSFORMATIONS

The Box and Cox transformations (see Appendix 2) taking as a model

$$y^1 = \{(y+1)^b - 1\} / b$$

where y^1 is the transformed and y the original value, gave values of b and standard errors of b as shown in Table 1. The range in b values is from 0.816 (b not significantly different from 1) to an extremely stringent -1.135. It should be noted that only 16 of the b values are significantly different from zero, and for the remainder the log $(y+1)$ transformation would have been permissible.

FIRST ORDER EFFECTS

Only significant effects are considered.

PORT/STARBOARD NETS

Fifteen species gave significant results and of these 12 gave higher catches with the port net and three with the starboard. The twelve port species are all bottom-dwelling or near bottom-dwelling and comprise: *Metapenaeus bennettiae*, *Portunus pelagicus*, *Penaeus plebejus*, *Sillago maculata*, *Portunus hastatoides*, *Callionymus limiceps*, *Metapenaeopsis*, *Centropogon*, *Sepia*, *Pseudorhombus arsius*, *Platycephalus* and *Phalangipus*. The three caught in significantly larger numbers

by the starboard net are midwater or pelagic species and comprise *Loligo*, *Hyperlophus* and *Trachurus*.

WITH/INTO TIDES

Only seven species gave significant effects (of which three are at the 5% significance level), and overall this is the least important sampling variable at the first order level. Four species gave higher catches with the tide (*Saurida undosquamis*, *Callionymus limiceps*, *Thrissocles*, and *Pseudorhombus arsius*) and three were higher into the tide (*Sphyraena*, *Spheroides pleurostictus* and *Dorippe*).

MIDDAY/DUSK

Thirty species gave significant effects, with eight giving higher midday catches. Five of the eight are probably midwater species (viz. *Paramonacanthus*, *Apogon*, *Loligo*, *Hyperlophus* and *Harengula*). The 22 species with higher dusk catches contain five species of penaeid prawns (*Metapenaeus bennettiae*, *M. endeavouri*, *Penaeus plebejus*, *P. esculentus*, and *Trachypenaeus*), three portunid crabs (*Portunus pelagicus*, *P. hastatoides* and *P. sanguinolentus*), two stomatopods (*Oratosquilla anomala*, and *Alima laevis*) and the crab *Dorippe*.

The remaining species occurring in greater numbers at dusk are primarily fish comprising *Sillago maculata*, *Pomatomus*, *Thrissocles*, *Apogonichthys*, *Johnius*, *Centropogon*, *Euristhmus*, *Spheroides hamiltoni*, *Priopidichthys* and *Suggrundus*; *Sepia* is also in this group.

It is of interest to note that in two pairs of fairly closely related taxa one occupies the 'daytime niche' and the other the 'dusk niche'. The species are *Spheroides pleurostictus* day and *S. hamiltoni* dusk, and *Odontodactylus* day and *Alima* night.

SITES

This is clearly the most important sampling variable at the first order level, with 55 species showing significant effects. The five species which failed to show effects are *Portunus pelagicus* (sp. 8), *Sepia* (sp. 37), *Scomberomorus* (sp. 39) *Spheroides hamiltoni* (sp. 46) and *Alpheus*

distinguendus (sp. 49). (Also four of these species failed to show second order interactions involving sites, the exception being *S. hamiltoni* with a midday-dusk/sites interaction at only 5% probability).

In Table 1 the sites with the largest mean (transformed) values are given and this shows 17 species with highest numbers at site 1, 9 at site 2 and 29 at site 3. Restricting consideration to these highest values can lead to a misleading grouping of species and a more representative picture is obtained by numerical classification. This was performed as follows: (a) using only the 55 species with significant site differences, (b) using mean transformed values of each species in each site, (c) standardising by totals to obtain proportionalities in each site and then (d) classifying species using Bray-Curtis dissimilarities and group-average sorting.

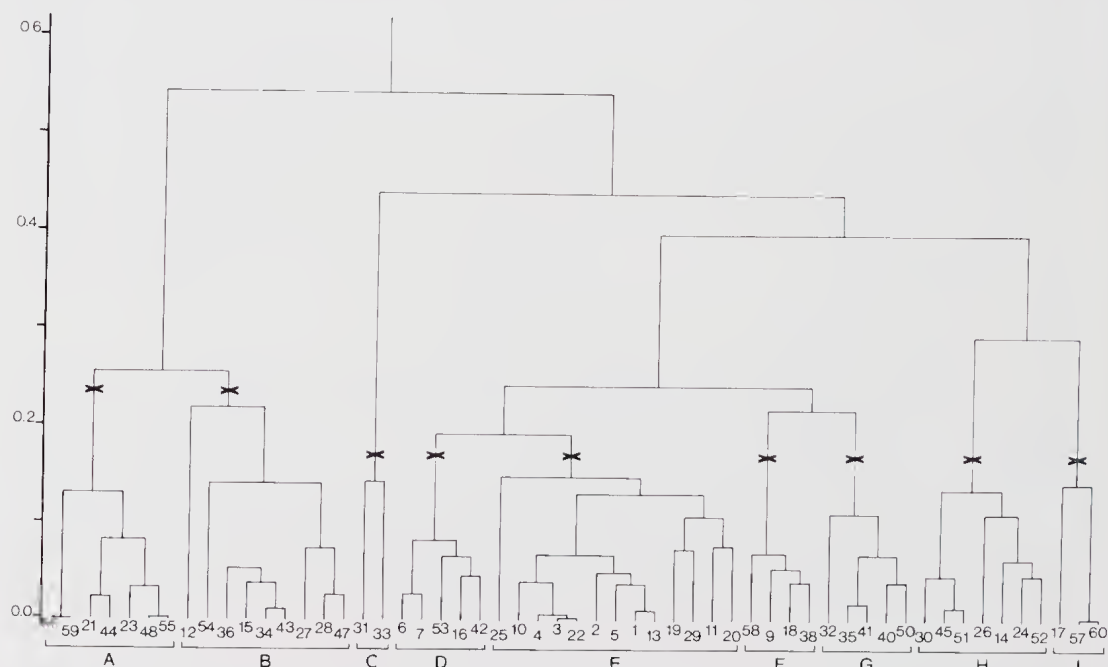


FIG. 2: Dendrogram showing classification of 55 species in the three sites. (For numbering of species see Appendix 1).

The species dendrogram which was obtained was interpreted at the nine group level, giving groups A-I, marked X in Fig. 2.

The proportional occurrences of species in the three sites were graded into H (high), M (medium) and L (low) and in Table 2 these grades in the nine species groups are given. This table shows that site 1 is characterised by high numbers

of the species in five species groups, site 2 by high numbers in two species groups (one very small), and site 3 by high numbers in three species groups. One of these last groups (species group A) contains a preponderance of rarer species. The largest species group (E) contains a preponderance of abundant species, and these occur in approximately coequal numbers in each site.

TABLE 2: TABULAR RESULTS OF CLASSIFICATION OF 55 SPECIES IN THREE SITES (SEE FIG. 2).

Species group	Species numbers from Appendix I	Graded Site 1	proportions Site 2	in sites Site 3
A	21, 23, 44, 48, 55, 56, 59	L	L	H
B	12, 15, 27, 28, 34, 36, 43, 47, 54	L	M	H
C	31, 33	L	H	L
D	6, 7, 16, 42, 53	H	H	L
E	1, 2, 3, 4, 5, 10, 11, 13, 19, 20, 22, 25, 29	M	M	M
F	9, 18, 38, 58	H	L	M
G	32, 35, 40, 41, 50	H	L	H
H	14, 24, 26, 30, 45, 51, 52	H	M	L
I	17, 57, 60	H	L	L

Species in groups A–I rearranged by code numbers; proportionalities of occurrences in the sites graded into H—high, M—medium and L—low.

SECOND ORDER EFFECTS INTERACTIONS

Only significant effects are considered. For convenience these are divided into 2 factor \times 2 factor and 2 factor \times 3 factor groups, the three factors being the sites. To assist interpretation, the linear interaction components of each cell in the respective 2 \times 2 and 2 \times 3 tables were obtained.

2 \times 2 INTERACTIONS

All cells in a 2 \times 2 linear interaction table have identical absolute values, and conceptual interpretations are necessarily restricted. The three 2 \times 2 interactions are:

- Port, starboard/with and against tide: no species involved (Hence not listed in Table 1).
- Port, starboard/midday, dusk: five species of which two are at the 5% probability level.

- With and against tides/midday, dusk: eight species, three at the 5% level.

Overall the 2 \times 2 interactions appear relatively unimportant.

2 \times 3 INTERACTIONS

From the linear interactions components one can select in each case the site giving the greatest interaction and which alternative state of the other factor is giving the higher catches. These are given in Table 1. The three 2 \times 3 interactions are:

- Port, starboard/sites: eight species, three at the 5% level. Three with unusual catches at site 1, four at site 2 and one at site 3; three species with high catches in the port, and five in the starboard net.
- With and against tide/sites: seven species, four at the 5% level. Two with unusual catches at site 1, four at site 2, and one at site 3; five species with high catches with the tide, and two against the tide.

- (c) Midday, dusk/sites: 22 species, only four at the 5% level. Fourteen with unusual catches at site 1, seven at site 2 and one at site 3; eleven species with high catches at midday and eleven at dusk.

DISCUSSION

Data on 60 species were summed over 13 times of sampling (1 year) and the effects of four remaining sampling variables were considered. The data were transformed to approximate normality using Box and Cox transformations and the range of power transformations required confirms the fact that the raw data did not conform to any standard distribution. One suspects that this applies generally to much marine data, and the choice of a single transformation (typically $\log(y+1)$) prior to analyses of such data appears objectionable.

First order effects of the four sampling variables showed that the number of species with significant differences was least when considering the with tide/against tide alternative (7 spp.). While possibly surprising, this result confirms Jones (1973) conclusions from work in Moreton Bay on nekto-benthic invertebrates. One third (21 out of 60) of the total number of species considered are relatively slow-swimming or non-swimming crustaceans which might be expected to occur more frequently in the with tide catches; there were no crustaceans amongst the seven species — all were fish. Also possibly surprising is the fact that species caught in significantly higher numbers in the two directions show no obvious relationships to modes of life. Rapidly swimming midwater fish (*Thrissocles* and *Sphyræna*) occur in each group. It seems likely that the with/against effects are due to random fluctuations in the data.

First order effects of port and starboard nets have already been briefly discussed. Fifteen species show significant effects and of these the three caught in significantly larger numbers in the starboard net are midwater species and the remaining twelve are bottom dwelling-species. There are various possible explanations for this difference, for example different net settings or different effects of propeller swirl. These are discussed further under port/starboard interactions with other variables.

Midday/dusk catches show important first order effects, with 30 species showing significant differences, eight giving higher midday catches and 22 higher dusk catches. Explanation of midday/dusk differences are offered in two main

directions, net avoidance and vertical movements of the species. At midday because of greater visibility, one might expect increased net avoidance, particularly by the more mobile species. In fact, of the eight species caught preferentially at midday, five are highly mobile (*Paramonacanthus*, *Apogon*, *Hyperlophus*, *Harengula* and *Loligo*). The five are probably primarily midwater species, and possibly the higher midday catches are due, fundamentally, to downwards movement during the daytime. It should be noted that three of the above species (*Paramonacanthus*, *Apogon* and *Loligo*), are amongst the four most abundant of the species in the catches and comprise 57% of the total catches.

The 22 species showing higher dusk catches contain eleven species of crustaceans. It is likely that these are buried by day and move above the substratum at dusk. The significantly higher dusk catches of five of the six species of penaeid prawns were to be expected since it is known that the Moreton Bay prawn fishery is mostly conducted from dusk to dawn. Nine of the species with higher dusk catches are fish, which presumably occur in high numbers in the water column during the day (the tenth fish *Suggrundus* is an exception). Possibly their concentration near the bottom at night is primarily to feed on nekto-benthic forms which have emerged from the substratum.

First order effects of sites show that this is the most important sampling variable, with significant differences in site catches in 55 out of the 60 species. We classified the data on the significant species in sites, thus reversing the usual procedures in which classification precedes tests of conformity. The results (see Table 2) have already been discussed briefly. Seventeen species occur in groups with lowest numbers at site 3 and 16 species in groups with highest numbers at site 3.

Interpretation of second order effects presents difficulties, particularly those involving 2 factor/2 factor interactions and these are now discussed. We first consider the possibility that the differences between port and starboard nets is due to the latter 'riding' somewhat higher. If so fishing into the tide should change the port/starboard differential, and lead to a noticeable port, starboard/with, against the tide interaction effect. In fact no species show significant interactions of this type. Assuming that at dusk several species of crustaceans move from the substratum into the water column, these should appear in larger numbers in the starboard net at dusk and lead to noticeable interaction involving port and

starboard/midday and dusk. In fact only five species show significant interactions.

We next consider 2 × 2 factor interactions involving midday and dusk. Visual stimuli for net avoidance will be stronger at midday than at dusk and this should result in differential effects with and against the tide (because hauls with the tide move faster over the bottom). Only eight species show significant with and against the tide/midday and dusk interactions and they include both highly mobile fishes (*Hyperlophus* and *Scomberomorus*) and relatively slow moving crustaceans (*Penaeus esculentus*, *Trachypenaeus*, *Oratosquilla woodmasoni* and *Thenus*).

We now consider 2 factor/3 sites interaction. The data shows that one species (52) is restricted to site 1, and four (44, 50, 51 and 54) are restricted to site 3. With such species the 2 factor recordings in the vacant sites are equal and interaction effects will necessarily be due to the occupied site. Of the total of thirty-seven 2 factor/3 site interactions five are accounted for in this way — three for species 51, one for species 52 and one for species 54. This leaves thirty-two 2 factor/3 factor interactions for consideration.

Of these six species show significant port, starboard/3 sites interactions. While intrinsically unlikely because of the lengths of the trawl warps, it is possible that part of the first order port/starboard effect is due to propellor swirl. If so there should be similar effects at the shallower sites 1 and 2, and interactions should be concentrated at site 3. In fact interactions are greatest at sites 1 and 2 in five of the six species which are involved.

Of the 32 interactions discussed above, only three involve with and into tides and sites. No rational explanation could be found for first order with/into effects, and it appears even more likely that interaction effects are due to randomness in the data.

Of the 29 significant midday, dusk/3 sites interactions, 11 involve higher midday catches and nine higher dusk catches. The ratio 11:9 is markedly different from the 8:22 ratio of midday/dusk species at the first order level. Restating the situation, the problem is why relatively few of the benthic, near benthic and benthic feeding species occur in significantly higher numbers at dusk in the shallower sites 1 and 2. No explanation can be offered.

Significant interactions are unevenly distributed among species, with over half the species (32 out of 60) giving no significant interaction, and four species (*Paramonacanthus*, *Penaeus esculentus*,

Metapenaeopsis and *Thenus*) giving 15. A third of the interactions is due to these four species.

In summary, attempts have been made to explain interactions in meaningful terms instead of invoking random variation, but in general these explanations appear invalid or at best unconvincing. In conjunction with the concentration of interactions within a few species, one must conclude that the vast bulk of the interactions are due to random events.

One of the important objectives of the present analyses was to determine which sampling variables could be regarded as replicates for the purposes of further times series analyses. Data from only two species (spp. 39, 49) can be so regarded over all sampling variables. Working on within-sites data another 18 species can be regarded as replicates over the three remaining sampling variables. Accepting that differences between with and into the tide samples are due to random variations, two further species (spp. 11, 30) can be added. For the remaining species summing recordings within sites will involve additions of values which are significantly different. The greatest differences will be between midday and dusk values and there are two practicable alternatives for later analyses: six analyses with midday and dusk/site combinations or three analyses each involving midday and dusk summations. The latter was chosen because division of catches into two components generally leads to impoverished data in each. This would be especially disadvantageous in the case of the 30 species for which significant differences between midday and dusk catches have not been demonstrated.

ACKNOWLEDGEMENTS

We are deeply grateful to the Department of Transport and Construction for financial support, to the trawler skipper Mr L. Wale for invaluable on board assistance, and to the systematics experts listed earlier.

APPENDIX 1

SPECIES CONSIDERED

CODE NO.	SPECIFIC NAME	SYSTEMATIC POSITION	NO. OF INDIVS	NO. OF CATCHES
1	<i>Paramonacanthus oblongus</i> (Temminck & Schlegel)	Monacanthidae, Pisces	44975	195
2	<i>Leiognathus moretoniensis</i> Ogilby	Leiognathidae, Pisces	18528	215

3	<i>Apogon quadrifasciatus</i> Cuvier & Valenciennes	Apogonidae, Pisces	9737	290	31	<i>Portunus sanguinolentus</i> (Herbst)	Portunidae, Crustacea	272	40
4	<i>Loligo formosana</i> Sasaki	Cephalopoda, Mollusca	8109	291	32	<i>Centropogon marmoratus</i> (Günther)	Scorpaenidae, Pisces	254	82
5	<i>Charybdis callianassa</i> (Herbst)	Portunidae, Crustacea	5207	194	33	<i>Alpheus stephensoni</i> Banner & Smalley	Alpheidae, Crustacea	229	28
6	<i>Polynemus multiradiatus</i> (Günther)	Polynemidae, Pisces	4718	213	34	<i>Trachurus mccullochi</i> Nichols	Carangidae, Pisces	227	43
7	<i>Metapenaeus bennettiae</i> Racek & Dall	Penaeidae, Crustacea	4276	165	35	<i>Selaroides leptolepis</i> (Cuvier)	Carangidae, Pisces	221	70
8	<i>Portunus pelagicus</i> (Linnaeus)	Portunidae, Crustacea	3253	279	36	<i>Charybdis truncata</i> Fabricius	Portunidae, Crustacea	172	60
9	<i>Penaeus plebejus</i> Hess	Penaeidae, Crustacea	2045	178	37	<i>Sepia aculeata</i> Orbigny	Cephalopoda, Mollusca	131	80
10	<i>Sillago maculata</i> (Quoy & Gaimard)	Sillaginidae, Pisces	1895	219	38	<i>Thalamita sima</i> H. Milne-Edwards	Portunidae, Crustacea	129	63
11	<i>Saurida undosquamis</i> (Richardson)	Synodontidae, Pisces	1559	141	39	<i>Scomberomorus queens- landicus</i> Munro	Scombridae, Pisces	122	59
12	<i>Portunus hastatoides</i> Fabricius	Portunidae, Crustacea	1247	138	40	<i>Pseudorhombus arsius</i> (Hamilton & Buchanan)	Bothidae, Pisces	110	60
13	<i>Pomatotus saltatrix</i> (Linnaeus)	Pomatotidae, Pisces	1086	159	41	<i>Upeneus tragula</i> (Richardson)	Mullidae, Pisces	110	54
14	<i>Hyperlophus trans- lucidus</i> McCulloch	Clupeidae, Pisces	747	94	42	<i>Euristhmus lepturus</i> (Günther)	Plotosidae, Pisces	101	57
15	<i>Callionymus limiceps</i> Ogilby	Callionymidae, Pisces	725	110	43	<i>Pseudorhombus</i> spp. (juveniles)	Bothidae, Pisces	99	50
16	<i>Thrissocles hamiltoni</i> (Gray)	Clupeidae, Pisces	636	85	44	<i>Metapenaeus endeavouri</i> (Schmitt)	Penaeidae, Crustacea	92	31
17	<i>Pelates quadrilineatus</i> (Bloch)	Theraponidae, Pisces	608	66	45	<i>Spheroides pleurostictus</i> (Günther)	Tetradontidae, Pisces	92	53
18	<i>Gerres ovatus</i> Günther	Gerridae, Pisces	572	96	46	<i>S. hamiltoni</i> (Gray & Richardson)	Tetradontidae, Pisces	87	58
19	<i>Caranx malam</i> (Bleeker)	Carangidae, Pisces	560	90	47	<i>Oratosquilla interrupta</i> (Kemp)	Stomatopoda, Crustacea	84	55
20	<i>Apogonichthys ellioti</i> (Day)	Apogonidae, Pisces	544	116	48	<i>Octopus membranaceus</i> Quoy & Gaimard	Cephalopoda, Mollusca	77	47
21	<i>Callionymus belcheri</i> Richardson	Callionymidae, Pisces	520	61	49	<i>Alpheus distinguendus</i> de Man	Alpheidae, Crustacea	76	37
22	<i>Penaeus esculentus</i> Haswell	Penaeidae, Crustacea	470	170	50	<i>Platycephalus indicus</i> (Linnaeus)	Platycephalidae, Pisces	74	53
23	<i>Metapenaeopsis novae- guinae</i> (Haswell)	Penaeidae, Crustacea	445	58	51	<i>Priopidichthys marianus</i> (Günther)	Centropomidae, Pisces	74	27
24	<i>Harengula castelnaui</i> (Ogilby)	Clupeidae, Pisces	440	49	52	<i>Alima laevis</i> (Hess)	Stomatopoda, Crustacea	70	41
25	<i>Trachypenaeus fulvus</i> Dall	Penaeidae, Crustacea	438	93	53	<i>Siganus spinus</i> (Linnaeus)	Siganidae, Pisces	60	38
26	<i>Johnius australis</i> (Günther)	Sciaenidae, Pisces	392	63	54	<i>Oratosquilla woodmasoni</i> (Kemp)	Stomatopoda, Crustacea	58	39
27	<i>Saurida tumbil</i> (Bloch)	Synodontidae, Pisces	381	76	55	<i>Sugggrundus harrisii</i> (McCulloch)	Platycephalidae, Pisces	52	33
28	<i>Priacanthus macracanthus</i> Cuvier	Priacanthidae, Pisces	323	82	56	<i>Minous versicolor</i> (Ogilby)	Scorpaenidae, Pisces	48	29
29	<i>Oratosquilla anomala</i> (Tweedie)	Stomatopoda, Crustacea	307	104	57	<i>Dorippe australiensis</i> Miers	Dorippidae, Crustacea	46	29
30	<i>Sphyræna obtusata</i> Cuvier & Valenciennes	Sphyrænidae, Pisces	281	57					

58	<i>Thenus orientalis</i> (Lund)	Scyllaridae, Crustacea	43	27
59	<i>Odontodactylus cultrifer</i> (White)	Stomatopoda, Crustacea	39	27
60	<i>Phalangipus australiensis</i> Rathbun	Majidae, Crustacea	38	27

APPENDIX 2

THE BOX-COX TRANSFORMATION

The Box-Cox transformations (Box & Cox 1964) constitute a family of transformations (including logarithms) of a dependent variable, instituted to obtain a transformation that most nearly satisfies the classical assumptions of least squares analyses of data. These assumptions are: (A) that the expected value of the dependent variable y should be a linear function of a set of p independent variables x_1, \dots, x_p and (B) that the errors are additive with constant variance. Hence, writing η for an error,

$$y = \beta_0 + \sum_{j=1}^p x_j \beta_j + \eta$$

Here the β_j 's are regression coefficients scaling the effect of the x_j 's on the dependent variable y and β_0 is the mean value of y at zero values of the independent variables.

By an appropriate choice of the x_j 's this formulation includes the models for regression, the analysis of variance and covariance, factorial designs etc. However, it is often preferable to look for transformations $y^1 = f(y)$ such that

$$y^1 = \gamma_0 + \sum_{j=1}^p x_j \gamma_j + \epsilon, \dots (1)$$

where the errors ϵ satisfy assumption (B) and the γ_j 's are regression coefficients. So in our choice of y^1 we attempt to find a scale on which y^1 satisfies conditions (A) and (B). In practice, the most useful transformations are powers and logarithms, often translated by a constant. The Box-Cox family of transformations is:

$$y^1 = (y+a)^b - 1/b, \text{ if } b \neq 0$$

or

$$y^1 = \ln(y+a), \text{ if } b=0$$

The use of y^1 rather than $(y+a)^b$ (for $b \neq 0$) ensures that the transformation $y^1 = \ln(y+a)$ gets smoothly into the family as b passes through zero. Box and Cox originally fixed a at zero and estimated b from data at hand. In the present case a was fixed at 1 to avoid logarithms of zero (corresponding to zero counts) in the classical manner. The alternative possibility of estimating

both a and b from the data complicates the analysis and was found in trial analyses on the present data to produce computational instability. This supports a sensible fixed choice of a . The value of b is found by maximum likelihood estimation. There are two principle approaches to this: first is the original method of Box and Cox and fits model (1) for a given b , adjusts b and repeats the procedure. Essentially, the value of b leading to the smallest sum of squared errors provides our estimate. The second is to use a numerical function maximisation routine based on the likelihood of the data and its first and second derivatives. We followed the second approach, utilising the Numerical Algorithms Group (1978) Library routine E04LBF. The source for an interactive FORTRAN program is available from the second author.

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